Real-Time Data Processing Onboard Remote Sensor Platforms

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***Abstract* - With EO-1 Hyperion and MightySat in orbit , and Warfighter-1 scheduled for launch this summer NASA and the DoD are showing their continued commitment to hyperspectral imaging (HSI). As HSI sensor technology continues to mature, the ever-increasing amounts of sensor data generated will result in a need for more costly communication and data handling systems. Lockheed Martin with experience in spacecraft design and expertise in developing special purpose onboard processors has teamed with Applied Signal & Image Technology (ASIT) who has an extensive heritage in HSI to develop a real-time and intelligent onboard processing (OBP) system that reduces HSI sensor downlink requirements. Our goal is to reduce the downlink requirement by a factor > 100, while retaining the necessary spectral fidelity of the sensor data needed to satisfy the many science, military, and intelligence goals of these systems. Our initial spectral compression experiments leverage commercial-off-the-shelf (COTS) spectral exploitation algorithms for segmentation, material identification and spectral compression that ASIT has developed. ASIT will also support the modification and integration of this COTS software into the OBP. Other commercially available COTS software for lossless spatial compression will also be employed as part of the overall compression processing sequence. Demonstrations of our initial capability will be presented at the August meeting.**

Over the next two years elements of a high-performance re-configurable OBP will be brass-boarded to implement proven preprocessing steps that distill the HSI data stream in both spectral and spatial dimensions. The system will intelligently reduce the volume of data that must be stored, transmitted to the ground, and processed while minimizing the loss of information.

I. INTRODUCTION

Our objective is to reduce spacecraft cost and increase the accessibility and utility of HSI data through appropriate use of onboard processing. Our strategy is to combine the processing expertise from ASIT, a leader in the HSI processing field and the developer of a library of HSI directed data compression and target detection algorithms, with the LM remote sensing, spacecraft and OBP capabilities. During the first eighteen months we are identifying, modifying and testing ASIT-developed algorithms as candidates for the OBP. We will then leverage the technologies available through LM to develop an OBP architecture concept that would support the throughput, flexibility and fidelity required by the sensor and the scientific community that use the data. Our heterogeneous OBP capability combines large processing throughput with a high degree of fidelity and reprogrammability by integrating state-of-the-art digital signal processors (DSPs), field programmable gate arrays (FPGAs), ASIC, and optical processing using high density interconnect (HDI) technology. This innovative combination of processing and packaging technologies will enable this processor to be used onboard the satellite as well as in analyst or mobile ground workstations.

Our technical effort began with studies to identify the algorithm functions that provide the best value as OBP processes. We will partition the processing requirements to the different elements of our initial DSP and FPGA processing architecture, develop both software and hardware-in-the-loop simulations for certain elements, and generate roadmaps.

II. SYSTEM CONCEPT

Figure 1 presents the HSI processing chain from sensor to finished HSI output products. Our OBP compression algorithms are designed to run unsupervised using only the data statistics to determine the compression transformation. The raw (level zero) sensor data are input to our directed data compression processing flow and compressed.

The compressed data are then transmitted to the ground where they are uncompressed, corrected to account for sensor calibration results thus converting raw to radiance data, and atmospheric absorption effects are removed from the spectra thus resulting in reflectance data. Material classification and identification can then be performed using standard techniques. This information can then be used to generate various image-based products; e.g., classification and abundance maps.

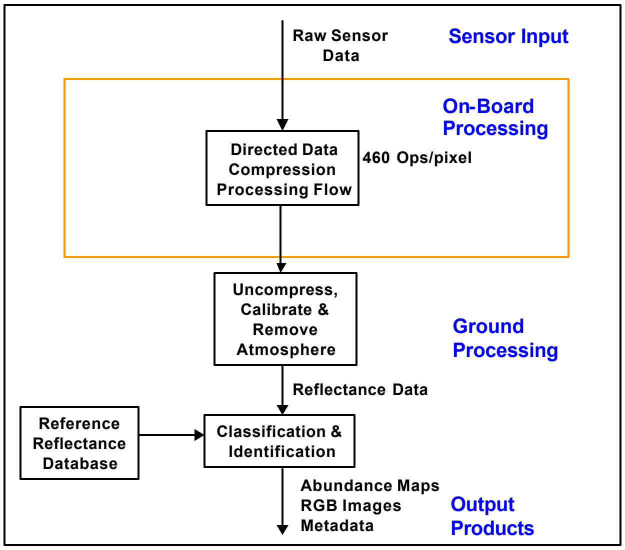

Figure 1 HSI Data Processing Chain

A top-level description of our directed data compression is presented in Figure 2. In step 1 dominant pixels are separated from anomalous pixels using the tunable anomaly detector as shown in Figure 3. This initial segmentation is important since dominant and anomalous pixels will be compressed differently; hence the name "directed data compression". This separation occurs by first determining the second order statistics and estimating the number of eigenvectors associated with the dominant pixels. The pixels that do not belong to the dominant subspace are automatically thresholded and so these pixels that have inherently large amounts of information content are labeled anomalous. The anomalous pixels are passed along to the Spectral Uniqueness Monitor (SUM) where the subset of spectral signatures required to describe all anomalous pixel are determined. These spectral signatures are the anomalous subspace endmembers. The automatic subspace discrimination function is then used to assign each anomalous pixel to one of the SUM derived classes.

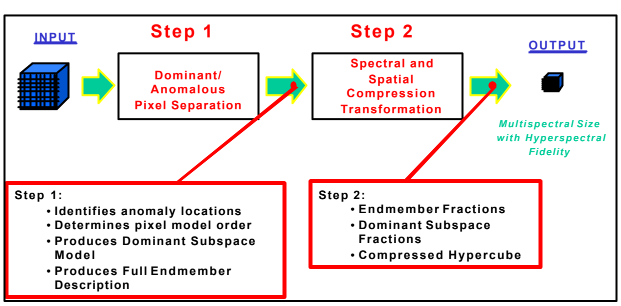

Figure 2 Directed Data Compression Approach

For Step 2 in Figure 2 the anomalous spectral basis signatures along with the dominant subspace eigenvectors are used together to formulate a compressing transformation in the spectral dimension, as shown in Figure 3. A lossless spatial compression algorithm is then applied to create the directed data compressed image cube.

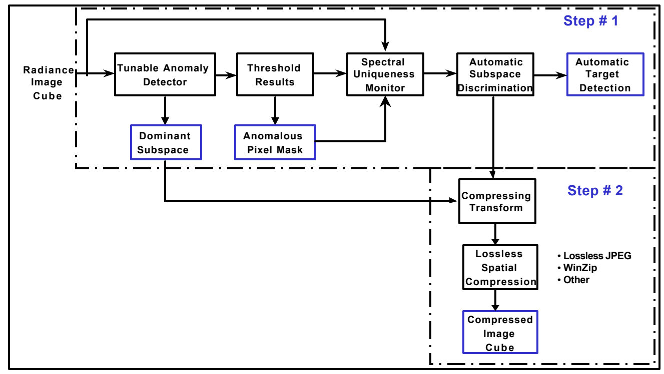

Figure 3 Directed Data Compression Processing Flow

III. PRELIMINARY EXAMPLE OF HSI DIRECTED DATA COMPRESSION RESULTS

Figure 4 shows a three-color composite resulting from the original data cube and the same cube compressed at 30:1 and 72:1. These results were generated using the directed data compression processing flow provided in Figure 3.

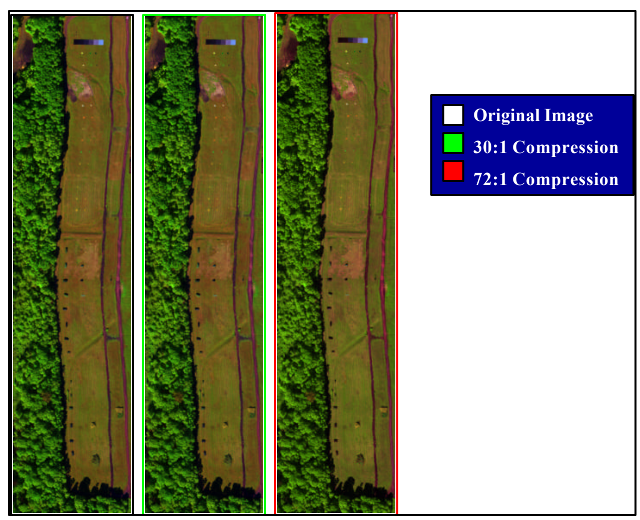

Figure 4 Directed Data Compression Example: Forest Radiance

Even though little or no visual differences can be observed in Figure 4 there are some spectral differences. These spectral differences can be observed by comparing the spectral angles noted in Figure 5 (angles, measured in degrees, determined by computing the spectral dot product) for corresponding pixels in the original and compressed data cubes. Small angles imply small differences in spectral data between the original and compressed data cubes. In addition to spectral angle comparisons, it is also possible to compare individual spectral features of compressed and uncompressed signatures. This type of comparison will be done in collaboration with EO-1 project scientists to ensure high value science information is not lost in the compression process.

Target	30:1 Comp.	72:1 Comp.
Fabric	1.87°	3.93°
Paint	3.04°	4.49°
Plastic	.0026°	.0012°
Tree	.91 °	1.83°
Soil	1.74°	4.42°
Grass	1.03°	2.40°

*Angular Separation Measured from Spectral Library:
- Target/Target: 2.5° - 4.5°
- Target/Background: >10°

- Spectral Angle Measure for several Targets and Backgrounds shown in degrees
- High Compression Ratios can yield High Fidelity spectra
- Degradation due to Compression is often less than Typical Target/Target and Target/Background Angular Separation*

Figure 5 Directed Data Compression

IV. HSI DATA COLLECTION

In order to properly test and evaluate the directed data compression algorithms HSI data consisting of a wide variety of known materials is needed. We are therefore planning a HyMap HSI data collection for the vicinity of Boulder Colorado. The HyMap sensor has a spatial resolution of about 5 meters with a 2.3 KM swath width and a 20 KM flight path length. The 20 KM flight path is broken into two segments as shown in Figure 6. The 1-2 flight path segment will consist of a treed mountainous region as well as the urban and residential. The 2-3 flight path segment will consist of residential and wet lands with reflectance panels and a ground spectrometer placed on table mountain at the end of the flight path.

HyMap Data Collection Scheduled for Mid-to-Late August

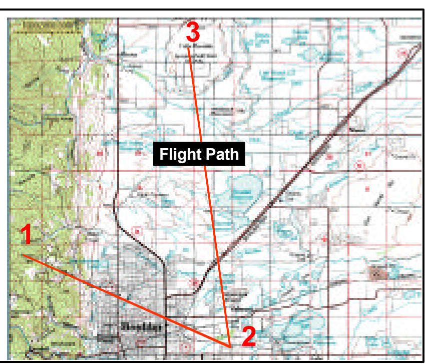

Figure 6 HSI Data Collection Flight Path

The reflectance panels and ground spectrometer will be used to verify the accuracy of atmospheric corrections to the data.

V. ONBOARD PROCESSOR (OBP) REQUIREMENTS

Approximately 460 floating point operations per pixel of input data are required to process the direct data processing flow specified in Figure 3. This information combined with specific sensor characteristics results in the OBP data processing requirements presented in Figure 7.

	Current Hyperion	Near Term	Continuous / Real -time Hyperion	Future*
Area Coverage Per Day (KM^2/day)	14.7 K	1.5 M	4.5 M	117 M
OBP Rate Requirement (GFLOPS)	0.02	2	6	160

Sensor Characteristics:
- Pixel Spatial Resolution – 30m
- # Spectral Bands – 220
- Sensor Data Rate – 150 mbps

Current Hyperion Operational Characteristics
- 6 Downlinks/day
- 2 Image Swaths per Downlink
- Image Swath Width – 7.65 KM
- Image Swath Length – 160 KM

*"Earth Science Enterprise Technology Planning Workshop on High Performance Spectrometry" May 12, 2000 (Hyperion Sensor Characteristics Except 250 KM Swath Width and SNR = 1000:1 VNIR and 500:1 NIR)

Figure 7 Onboard Processor Requirements

For the EO-1 Hyperion sensor under the current operational environment the minimum requirement for an OBP to keep up with the data on a daily basis is 0.02 GFLOPS. Since our goal is to compress the data by a factor of 100:1 a Hyperion sensor could theoretically be tasked to increase its coverage by a factor of 100 without increasing the telemetry requirements with the OBP requirement of 2 GFLOPS. If the Hyperion sensor is operated continuously then the OBP requirement becomes 6 GFLOPS. NASA Scientists at the May 2000 meeting of "Earth Science Enterprise Technology Planning Workshop on High Performance Spectrometry" specified a HSI sensor with similar sensor characteristics to the Hyperion except with much improved noise characteristics and the swath increased from 7.5 KM to 250 km. The OBP requirement to operate this sensor continuously would be 160 GFLOPS. The algorithms that are being used for this effort are highly vectorized which allows for parallel implementation. The techniques also take advantage of linear algebra functions such as vector dot product, matrix multiply, eigenvector decomposition, and singular value decomposition. Given these algorithm attributes, it is clear that a combination of a general purpose computer that shares memory with standard digital signal processing and field programmable gate array (FPGA) architectures can be used to demonstrate an on-board hyperspectral processing capability.

VI. PROJECT SCHEDULE AND TRL VALUES

Our project schedule is presented in Figure 8. The schedule includes the firsts two years of the primary contract as well as the third year option. The first eighteen months will be dedicated to developing, testing and evaluating directed data compression algorithms The last 18 months will focus on implementing elements of the directed data compression algorithm in special purpose electronic hardware; i.e., DSP and FPGA electronic chips.

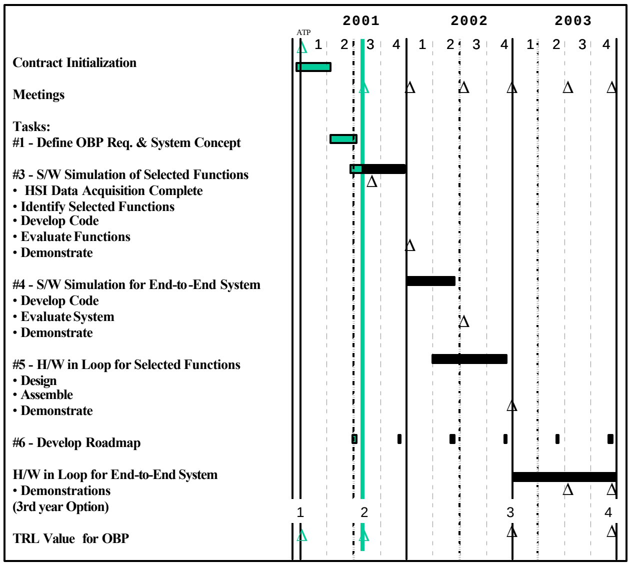

Figure 8 AIST Contract Schedule and System TRL Values

At the beginning of this contract the maturity level of the OBP system consisted of an abstract concept of basic principles resulting in the TRL value for the system of 1 We have made rapid progress on the effort through the use of HSI tools that ASIT has developed and the DSP and FPGA electronic processor chips that are quite mature At the Interim Review we demonstrated the feasibility of directed data compression on various hyperspectral data sets, thus the system TRL value was increased to 2. We predict by the end of the second year our concept will have been further validated by simulation and we will have demonstrated technical feasibility using a breadboard implementation. At this time, we expect the TRL value to be increased to 3. At the end of the third year our breadboard OBP system will have been validated in a laboratory environment using full data sets resulting in a TRL value of 4.

VII. CONCLUSIONS

We have now defined and demonstrated approach to compress HSI data, and have shown that we can compress these data 100:1 without obvious visual degradation. When we compare the spectra of corresponding pixels between compressed and uncompressed data cubes we observe angular differences and other slight changes in spectral features. The significance of these differences is currently unknown. We are requesting that NASA scientists support us in evaluating the significance of the differences between the compressed and uncompressed data cubes, so that important science data is not lost. The compression process can be set up to provide variable compression rates depending on the particular science objectives.

We are currently recommending that for this contract the design requirement for the OBP be 2 GFLOPS as indicated by the highlighted green box in Figure 7. We believe that digital signal processor (DSP) and field programmable gate array (FPGA) technology in combination with high density interconnect (HDI) packaging technology can satisfy this OBP requirement. Enabling technologies; e.g., application-specific integrated circuits (ASIC) and optical processors, are available to address future OBP requirements.

ACKNOWLEDGMENTS

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REFERENCES

Harsanyi, J. C., (1993), *Detection and Classification of Subpixel Spectral Signatures in Hyperspectral Image Sequences*, Ph.D. Dissertation, University of Maryland, Baltimore County, 116 pp.

Harsanyi, J. C. and C. Chang, "Hyperspectral Image Classification and Dimensionality Reduction: An Orthogonal Subspace Projection Approach," *IEEE Transactions on Geoscience and Remote Sensing*, July, 1994.

Harsanyi, J. C. and C. Chang, " Hyperspectral Image Dimensionality Reduction and Pixel Classification: An Orthogonal Subspace Projection Approach," *Proceedings of the Twenty-seventh Annual Conference on Information Sciences and Systems*, pp. 401-406, Mar 24-26, 1993.

Harsanyi, J. C., W. H. Farrand, C. Chang, "Detection of Subpixel Signatures in Hyperspectral Image Sequences," *1994 ASPRS/ACSM Annual Convention and Exposition Technical Papers, Reno, Nevada*, vol. 1, pp. 236-247, Apr. 25 -28, 1994.